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May 1, 1998

The Honorable Philip R. Recht
Deputy Administrator
NATIONAL HIGHWAY TRAFFIC
SAFETY ADMINISTRATION
400 Seventh Street, S. W., Room 5220
Washington, DC 20590

DEPARTMENT OF TRANSPORTATION
98 JUN 17 PM 3:01
DOCKET SECTION

Dear Mr. Recht:

Re: **Settlement Agreement**
Section D. Crash Test Dummy Research

Enclosed is a presentation authored by Warren N. Hardy and Lawrence W. Schneider of the University of Michigan entitled "Methods for the Investigation of Impact-Induced Abdominal Injuries." This relates to Project D .2 (a) Development/Refinement of Abdominal Response Corridors and Tissue Properties. It was presented at the 25th International Workshop on Human Subject for Biomechanical Research on November 15, 1997.

As you will note, the Acknowledgment did not conform to the language required by the settlement agreement. The authors have been informed of this and have been provided with the appropriate words to use in any further publication or presentation.

Sincerely,

David A. Collins
Attorney

c: James A. Durkin, Esq.

Enclosure

Methods for the Investigation of Impact-Induced Abdominal Injuries

Warren N. Hardy
Lawrence W. Schneider
Biosciences Division
University of Michigan
Transportation Research Institute

Hardy and Schneider, 1997.



*November 15, 1997
Lake Buena Vista, Florida*

25th HSBR
International
Workshop

Overview

- ▶ Review of abdominal response information -
 - Pertinent literature and data
 - Alternate treatment of existing data
 - Remarks
- ▶ Summary of associated issues
- ▶ Discussion of current approach
 - General protocol
 - General preparation
 - Measurements
- ▶ Preliminary findings

Hardy and Schneider, 1997.



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Pertinent Response Data

- ▶ SAE J1460-1 (1995)
- ▶ Cavanaugh, et al. (1986)
- ▶ Nusholtz, et al. (1994)
- ▶ Viano, et al. (1989)
- ▶ Stalnaker, et al. (1985)
- ▶ Rouhana, et al. (1989, 1990)

Hardy and Schneider, 1997.



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Pertinent Literature

- ▶ Literature review with particular emphasis on -
 - Abdominal impact response
 - Abdominal tissue properties
 - Epidemiology and accident data pertaining to abdominal injury -
 - Steering wheel/column-impact injuries
 - Belt-loading injuries
 - Airbag-interaction injuries

Hardy and Schneider, 1997.



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Hardy and Schneider, 1997.



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Cavanaugh, et al. 1986

- ▶ **Subjects -**
 - 12 unembalmed repressurized human cadavers
 - 8 male, 4 female, averaging 54.7 yrs., 70.3 kg, 167 cm
- ▶ **Impacts -**
 - Level of L3, seated posture, free back
 - Rigid bar (2.5 cm dia.), 31.5 and 63.5 kg impactors
 - Two speeds, 6.1 m/s (4.9 - 7.2) and 10.4 (8.5 - 13.0)
- ▶ **Remarks -**
 - Deflection measured from film (peak @ 66% compression)
 - Equal-stress/equal-velocity scaling (heavy reliance)
 - Stiffness proportional to speed and mass
 - Loading a simple ramp, unloading a vertical line

Hardy and Schneider, 1997.



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Nusholtz, et al. 1994

- ▶ **Subjects -**
 - 6 unembalmed repressurized human cadavers
 - 3 male, 3 female, averaging 54.7 yrs., 58.3 kg, 172 cm
- ▶ **Impacts -**
 - Level of L2, seated posture, free back
 - Angled semicircular tube (2.5 cm dia.), 18 kg impactors
 - Two speeds, 6.0 m/s (3.9 - 7.5) and 10.0 (9.3 - 10.8)
- ▶ **Remarks -**
 - Deflection measured from film and acceleration data
 - No rate dependence found
 - Low pendulum mass, small sample size, subject variability
 - Off-axis and multidimensional loading after peak force

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Viano, et al. 1989

- ▶ **Subjects -**
 - ▀ Unembalmed repressurized human cadavers
 - ▀ Averaging 53.8 yrs., 67.2 kg
- ▶ **Impacts -**
 - ▀ Thorax (16), pelvis (14), abdomen (14) 7.5 cm below xiphoid
 - ▀ Suspended posture, 30 deg. to right or left of midline, through c.g.
 - ▀ 15.2 cm rigid disk, 23.4 kg impactor, arrested after 15 cm
 - ▀ Three speeds, 4.5 (6), 6.7 (4), 9.4 (4) m/s
- ▶ **Remarks -**
 - ▀ Deflection measured from 3D film analysis
 - ▀ Equal-stress/equal-velocity scaling (renormalized for speed)
 - ▀ Response characterized by initial stiffness and plateau force

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Stalnaker, et al. 1985

- ▶ **Subjects -**
 - ▀ Anesthetized primates (vervet, rhesus, baboon and squirrel)
 - ▀ From previous studies of Beckman, 1971 (16 frontal) Stalnaker, 1971 (17 right and left) Trollope, 1973 (2 lateral, 7 frontal)
- ▶ **Impacts -**
 - ▀ Upper, middle, and lower abdomen, seated posture, free back
 - ▀ Various rectangular bar and wedge impactors
 - ▀ Speeds from 8.4 - 17.0 m/s
- ▶ **Remarks -**
 - ▀ Three-stage response: rise (I), plateau (II), rise (III)
 - ▀ Linear velocity scaling, extrapolation from animal to human
 - ▀ All data averaged: impact region/direction/pendulum differences

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Rouhana, et al. 1989, 1990

- ▶ **Subjects -**
 - 15 Swine cadavers, 43.6 kg
 - 25 anesthetized swine from previous study (Miller, 1989), 46.1 kg
- ▶ **Impacts -**
 - Level of L4 (~ human L3), supine posture, supported back
 - Seatbelt yolk fixture, controlled stroke MTS
 - Two speed ranges, 0.2 - 5.3 m/s (cad.), 2.0 - 7.0 m/s (anesth.)
- ▶ **Remarks -**
 - Actuator deflection and belt stretch measured
 - Cadaver and anesthetized swine data compared
 - Human cadaver data reviewed
 - Frangible abdomen designed

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Alternate Treatment of Data

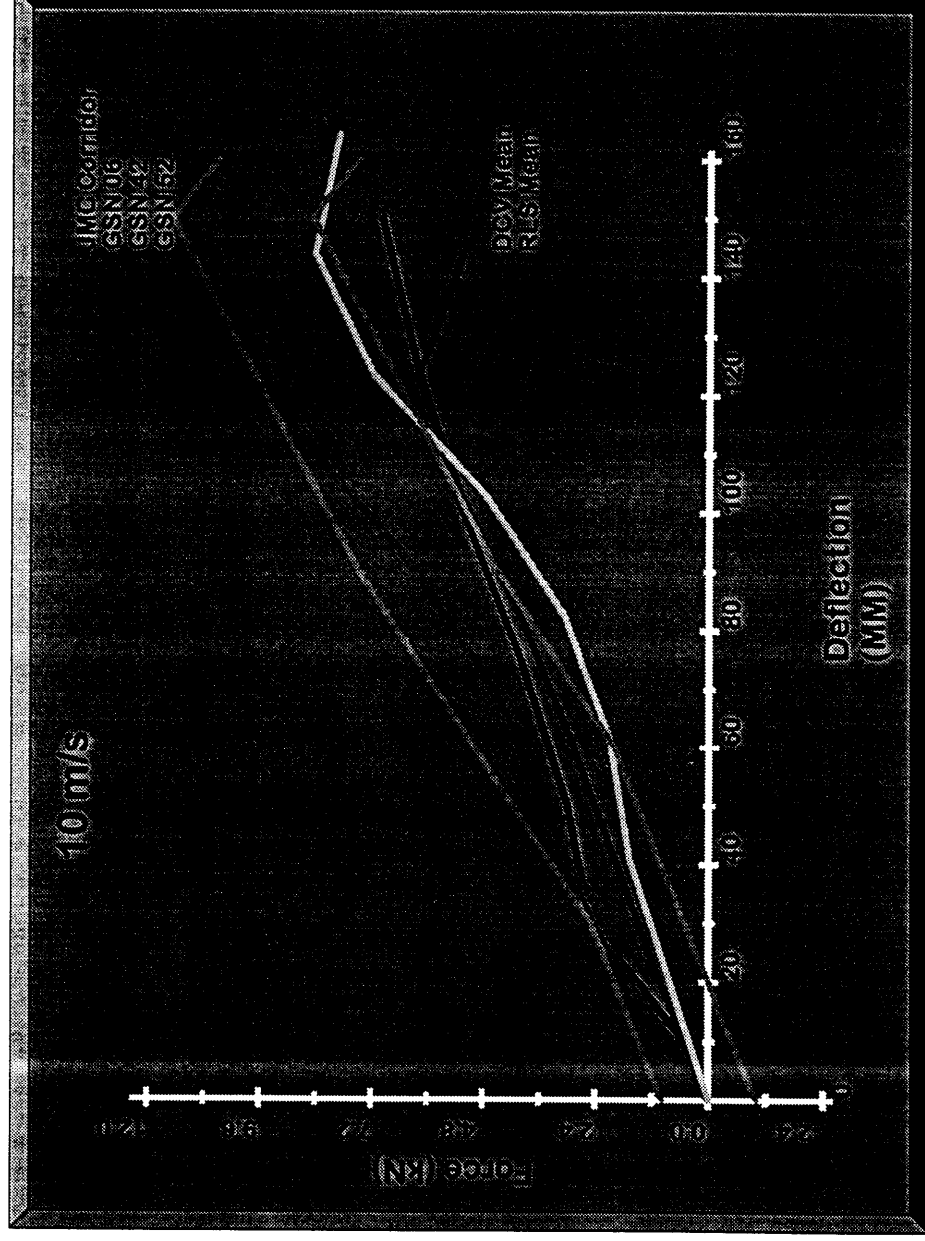
- ▶ Nusholtz data split into two “corridors” -
 - Applied equal-stress/equal-velocity scaling
- ▶ Viano data averaged data within 6.7 and 9.4 m/s ranges
- ▶ Stalnaker upper-abdomen data eliminated
 - Selected impacts @ 10 m/s (7), averaged all species
 - Generated stages I, II, and III using 9.6 % and 27 % compression break points, normalized to 28.9 cm abdominal depth
 - Used velocity scaling to generate 6 m/s curve
- ▶ Cavanaugh and Rouhana data plotted to overlay other data

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Comparison of Existing Force-Deflection Data

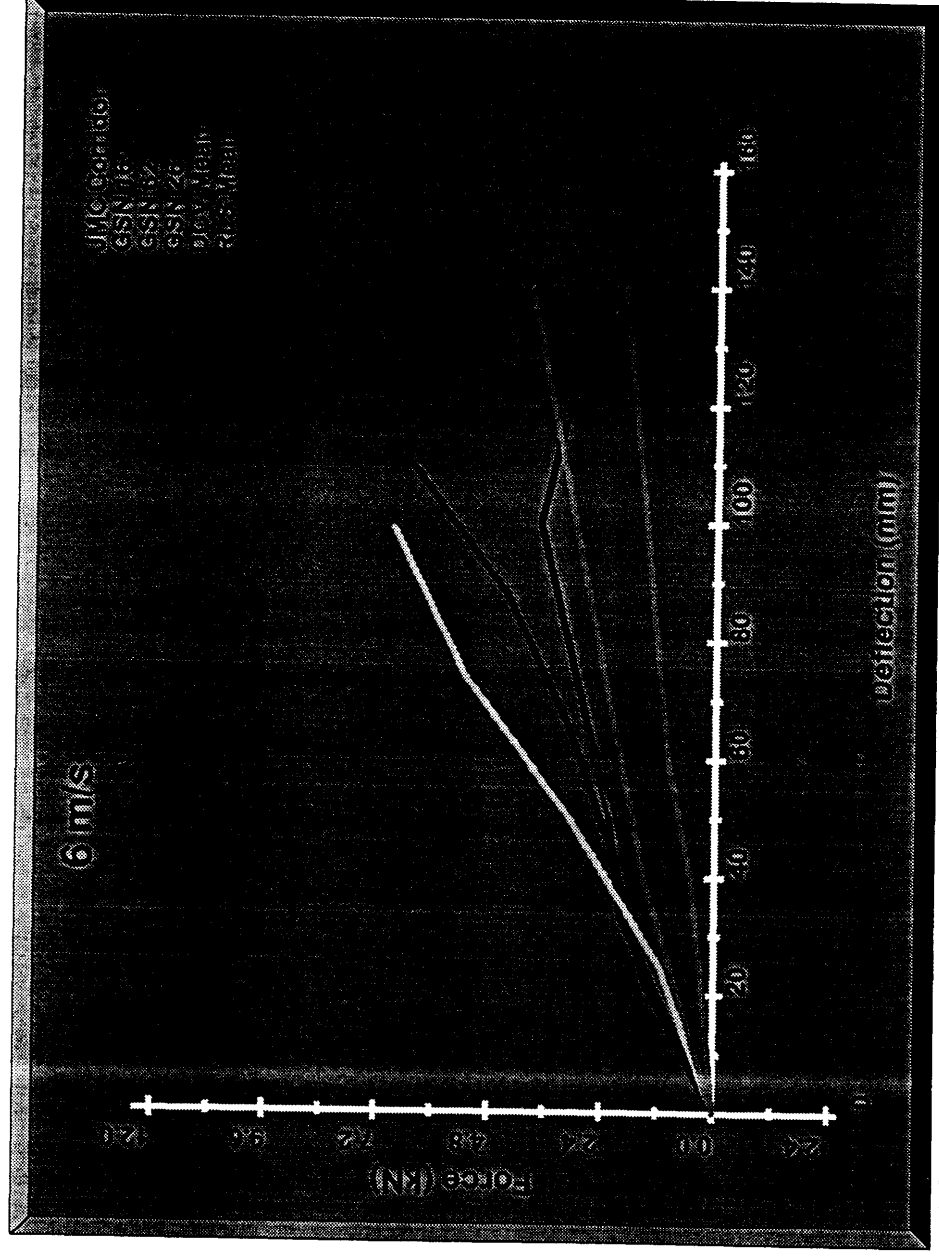


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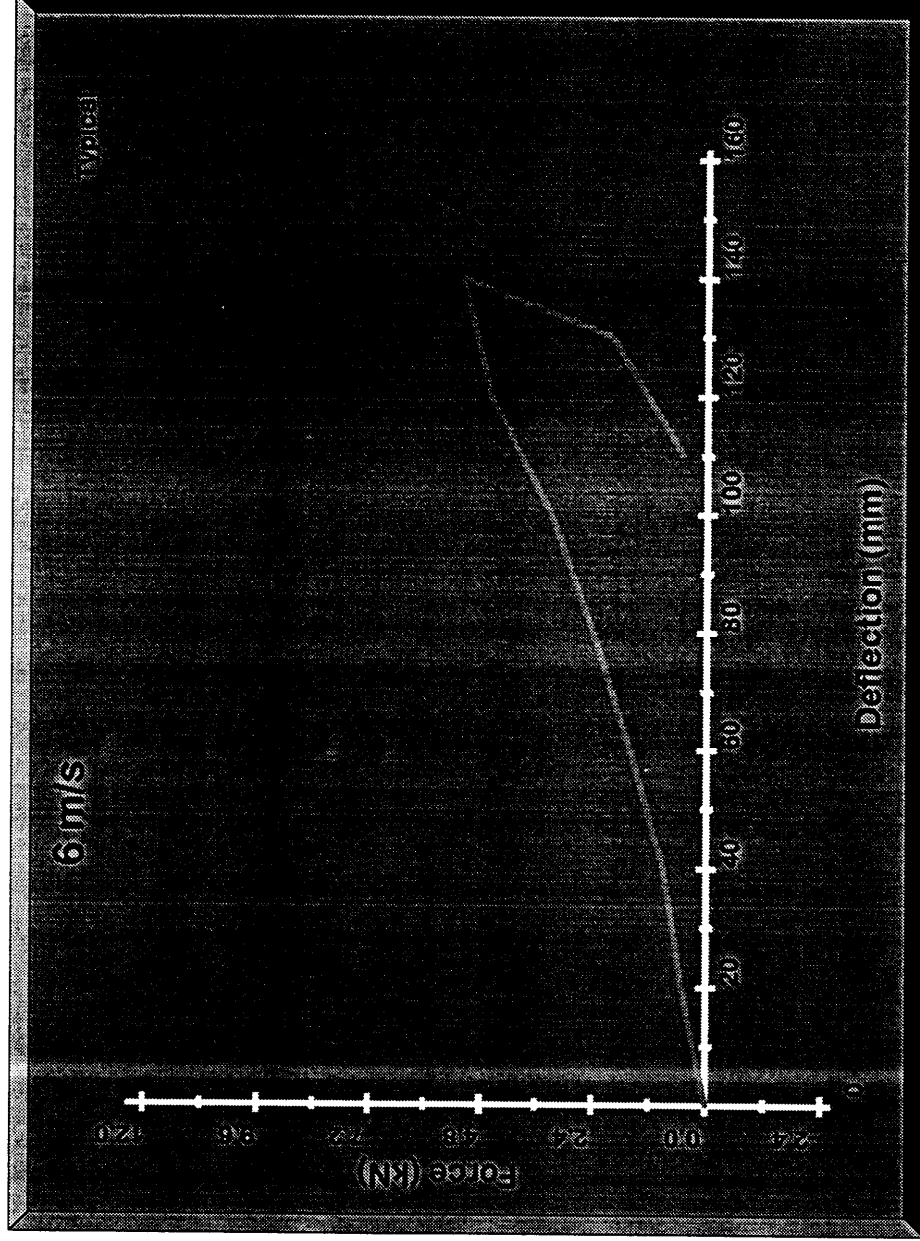
Comparison of Existing Force-Deflection Data



Hardy and Schneider, 1997.



Force-Deflection Response of Frangible Absorbent



Hardy and Schneider, 1997.



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Remarks

- ▶ Rate effects: relative impactor/subject mass
- ▶ Loading response: impactor shape
- ▶ Hysteresis response: impact location
- ▶ Special attention paid to -
 - Organ turgor effects
 - Initial (postural) effects

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Summary of Associated Issues

- ▶ **Key issues, objectives and priorities -**
 - Resolution of rate-sensitivity issues (mass)
 - Isolation of contribution of ribs (location)
 - Determination of response shape (face)
 - Identification of influence of peritoneum
 - Examination of posture and initial-condition effects
 - Mapping of abdominal response by region
 - Investigation of perfusion related topics
 - Temperature sensitivity
 - Organ turgor
 - Respiration effects
 - Soft-tissue injury

Hardy and Schneider, 1997.



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Discussion of Approach

- ▶ Rigid impact
- ▶ Restraint loading
- ▶ Tissue/structure properties/contributions

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General Protocol

► Rigid bar impacts -

- 2.5 cm round straight bar, 46 cm long
- 48 kg impactor
- 2 levels (mid and upper abdomen)
- 3 speeds: 9.0, 6.7, 4.4 m/s

► Rigid disk impacts -

- 7.5 cm round flat face
- 48 kg impactor
- 7 regions (excluding inguinal regions)
- 3 speeds: 2.2, 4.4, 6.7 m/s
- Incremental impacts possible

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General Protocol

- ▶ Fresh cadavers -
 - Seated upright
 - Free back
 - Rounded table front
 - Teflon skid
 - Plastic diaper
- ▶ Necropsy
- ▶ Evaluation of various injury criteria

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General Preparation

- ▶ **Perfusion -**
 - **Bilateral ascending and descending**
 - **Carotid supply (100 mmHg)**
 - **Jugular return**
 - **Heated normal saline with indicator**
- ▶ **Tracheotomy -**
 - **Full “breaths” prior to impact**
- ▶ **Contact event -**
 - **Thin foil**
 - **Solid state (LEDs at lens)**

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Dynamic Measurements

- ▶ **Pendulum loads (3F & 2 M)**
- ▶ **Abdominal pressures -**
 - **Descending aorta (left femoral artery)**
 - **Sigmoid (descending) colon**
 - **Bladder (250 ml normal saline)**
 - **Stomach**

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Kinematic Measurements

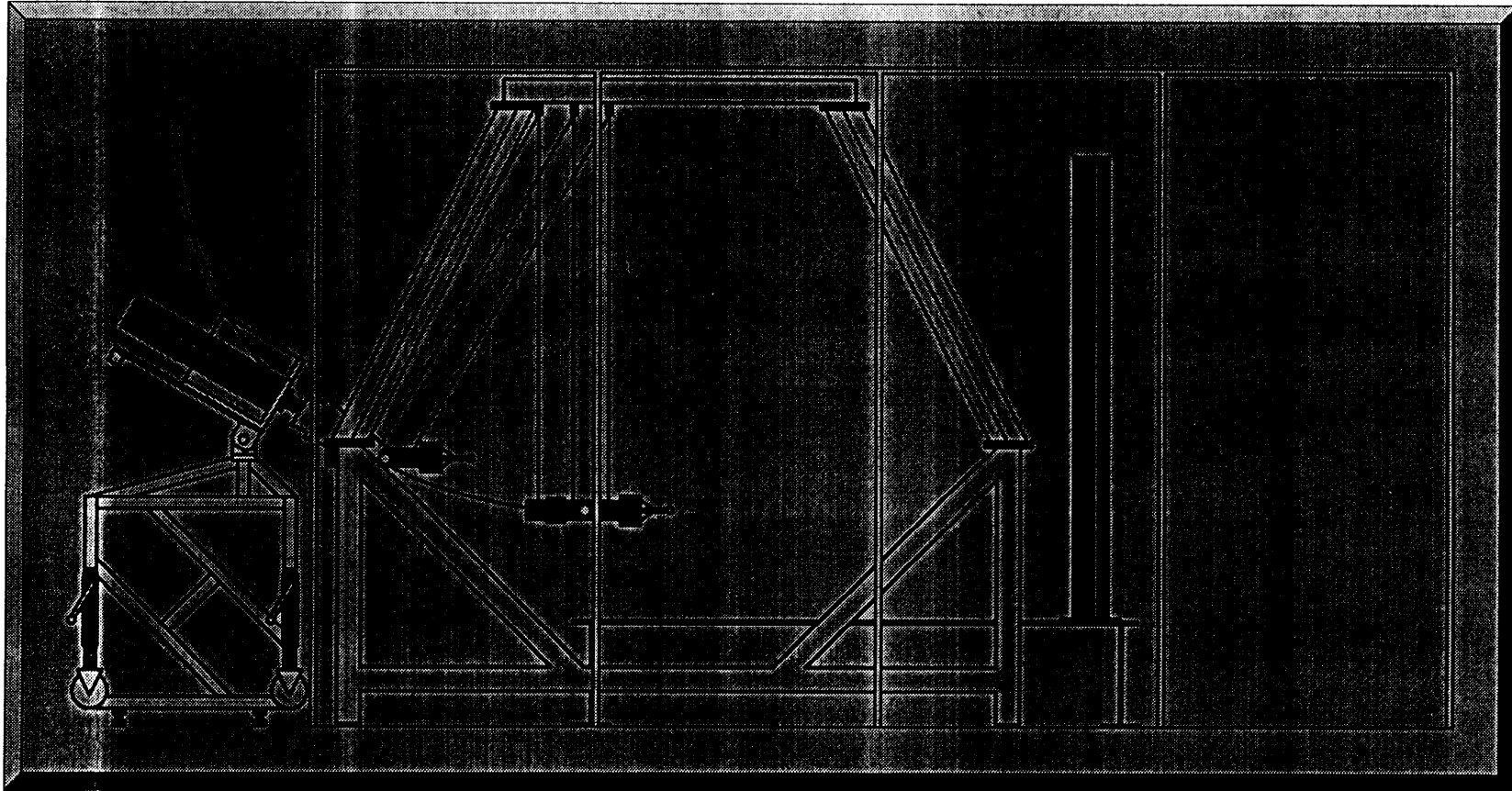
- ▶ **Acceleration -**
 - Pendulum (x (2))
 - T1, T11, L3, S1, Sternum (x & z)
- ▶ **Velocity -**
 - KC Laser trap (pendulum)
- ▶ **Displacement -**
 - Pendulum
 - T1, T11, L3, S1, Sternum (2 targets)
 - Lateral and overhead cameras (1 kfps)

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Abdominal Impact Scheme

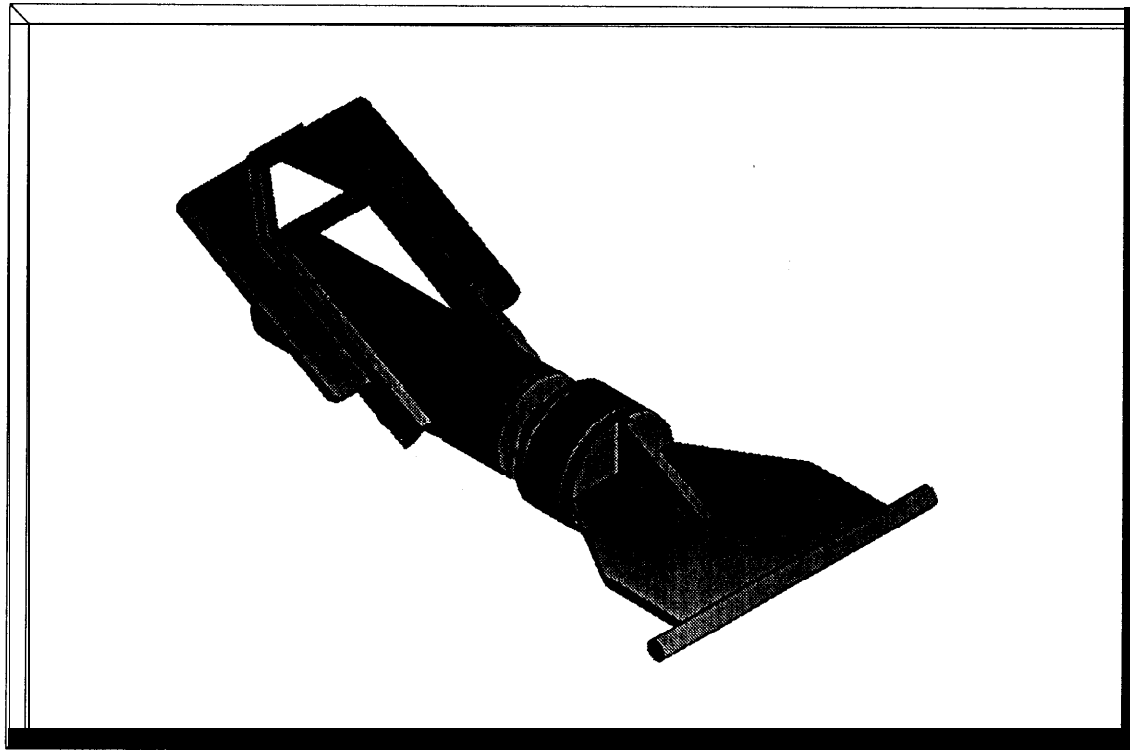


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Impact Pendulum

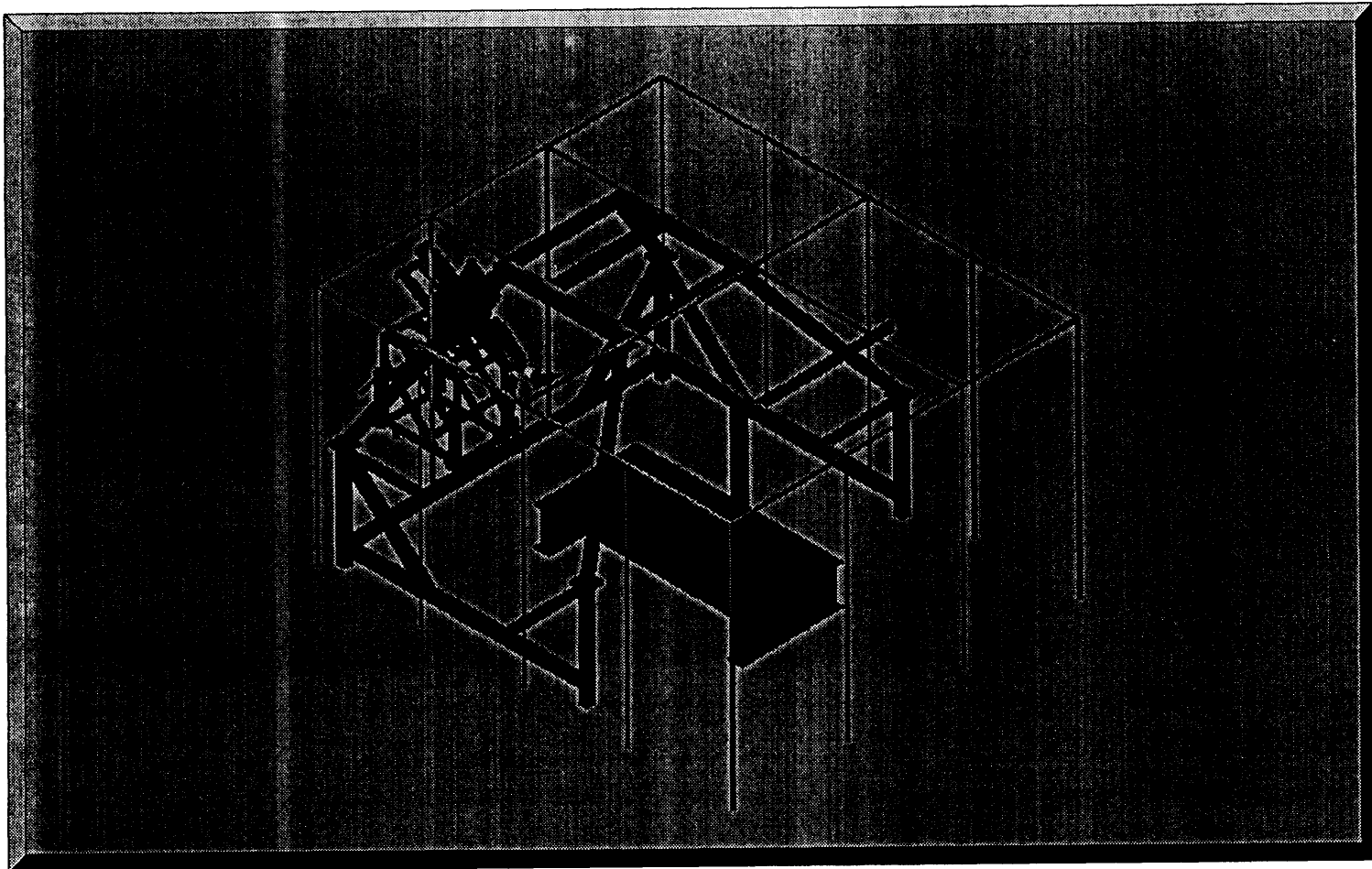


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Airlock Cadaver Testing Area



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Tissue Testing

- ▶ Objective -
 - Obtain dynamic material properties of -
 - Peritoneum
 - Omentum
 - Diaphragm
 - Solid/hollow organs
- ▶ Protocol -
 - Preconditioning at quasi-static rate
 - Stress relaxation
 - Creep
 - Dynamic failure at rates of 1, 4.3, 6.7 m/s
 - Map results to viscoelastic model

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Acknowledgment

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Photographs Available Upon Request

For photographs, contact:

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